

QUICK REPORT ON THE SEPTEMBER 26, 2003 TOKACHI-OKI EARTHQUAKE, JAPAN

Rupture Process of the 2003 Tokachi-oki Earthquake Obtained from Strong Motion Data of K-NET

The Tokachi-oki Earthquake (Mw 8.0), struck Hokkaido in the early morning of 26 September 2003 at 4:50 a.m. local time (JST). Its ground motion was recorded at 655 stations of nationwide strong motion networks, K-NET and KiK-net. The maximum peak ground motion, 970 gal, was observed at station HKD100 and large amplitudes were observed in a wide area of Eastern-Hokkaido.

Data and method

We estimated the rupture process from strong motion data of 13 stations (Figure 1) with multi-time linear inversion method. Theoretical waveforms were calculated by the discrete wavenumber method with a 1-D layered medium. The observed acceleration records were integrated into velocity and bandpass filtered between 0.02 - 0.2 Hz. We inverted 85 sec of the S-wave portion (from 5sec before to 80 sec after S-wave arrivals).

Finite fault model

A fault model was assumed as follows,

- (1) The epicenter determined by JMA (41.7795N, 144.0785E)
- (2) The focal depth and the strike angle from a CMT solution with F-net records (29 km and 246 degrees)
- (3) The dip angle and the fault area inferred from the aftershock distributions (20 degrees and 140km x 160km).

Results

Figure 1 shows the estimated total slip distribution, which consists of two major slip areas; (a) around epicenter and (b) the north-west part of the fault with the maximum slip of 7.1 m. Relatively small slip velocity (~ 0.75 m/s) and long slip duration (nearly 13 sec) are obtained at region (a). This corresponds to the fact that onsets of direct waves were obscure in many observed seismograms.

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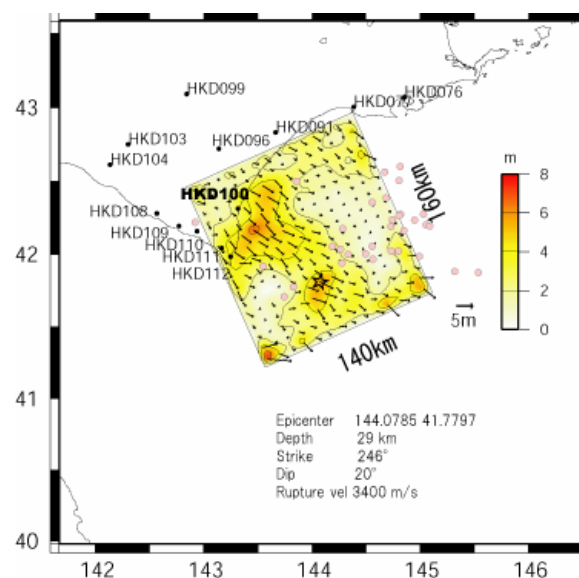


Figure 1 Estimated slip distribution on the fault plane. Colored circles are thrust type aftershocks. The star shows the epicenter. Arrows indicate the amplitude and direction of slip.

Tsunamis Caused by the Tokachi-oki Earthquake

The Tokachi-oki Earthquake in 2003 generated a series of tsunamis. The main shock occurred at 4:50 (JST) on 26 September. The tsunamis were observed on the Pacific coasts from Hokkaido to the Tohoku region in Japan. Many researchers including members of PARI conducted tsunami field survey started at the same day, when the main shock occurred. The highest evidence of tsunami run-up was found at Cape Erimo and it was 4.0m. The tsunami height of 2.5m was observed at the tide station in the Tokachi Port at 5:24 (JST) about 30 minutes after the main shock. After the tsunamis arrived at the coasts in Hokkaido, they propagated along the coasts like edge waves and a number of tsunami attacked the coasts. At the Kushiro Port, the first tsunami of 1m arrived at 5:06 (JST), the maximum tsunami of 1.2m observed at 9:03 (JST) and a 1m tsunami attacked again at 14:20 (JST). At that time tsunami inundation occurred because the tsunami added to the normal high tide and the resultant sea level became high. At the Tokachi River, the tsunamis ran up 11km from the river mouth.

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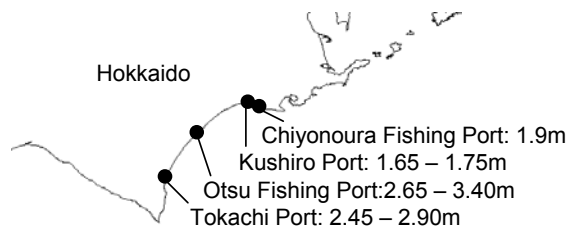


Figure 2 Tsunami run-up measured by PARI



Photo 1 Evidence of tsunami run-up at Tokachi Port

Falling Down of Ceiling of Kushiro Airport Terminal Building

The Tokachi-oki Earthquake in 2003 occurred in the early morning on September 26, 2003, which caused large-scale falling down of departure lobby ceiling of the Kushiro airport terminal building. The Building Research Institute (Building Research Institute) and the National Institute for Land and Infrastructure Management (National Institute for Land and Infrastructure Management) surveyed the earthquake damage.

The terminal building (structural steel) was three stories with 19.6 m in total height. The departure lobby was open ceiling and covered by a 9.7 m high ceiling with 36 m in length (north-south direction) and 18 m in width (east-west direction). The supporting system of the ceiling was a Japanese traditional one, that is, the 12 mm thick rock wool acoustic board on the 9 mm thick plaster board substrate screwed to the light gage structural steel members was hanged by hanger rods. The hanger rods were placed every 1.1 m x 0.9 m and every four hanger rods in each direction were braced to reduce pendulum displacement.

The three edges (north, south and east) of the ceiling were separated from surrounding structural elements and only the west edge was rigidly connected to the structure. Due to the pounding of the ceiling to the west structural frame, a large area of the ceiling fell down. No one was injured due to the early morning shock.

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Photo 2 Outside view of airport terminal building



Photo 3 Damaged ceiling

Damage to River Dikes

River dikes in Obihiro area including Tokachi river, Urahoro-Tokachi river and Usikubibetsu river were severely damaged during the earthquake. The total length of the damaged dike adds up to more than 25 km. Typical layout of the dikes in the area, particularly for the dikes of Tokachi river, has geometry of 5-10 m wide crest, 4-8 m height and gentle slope angle of 1:5. The observed damage to the dikes is mostly longitudinal crack and settlement of crests and lateral spreading of the gentle slopes as shown in Photo 4. The similar damage to the dikes in this particular area was observed during the 1993 Kushiro-oki earthquake.

In this area, extremely soft peat soil prevails the ground surface and ground water table are close to the ground surface. The dikes in this area, which were constructed using sandy soils, have significantly settled, causing the base of the dikes penetrated into the foundation soil. The mechanism and the main cause of the damage to the dikes is presumed to be liquefaction of the dike material below the ground water table, which is similar to that during the 1993 event.

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Photo 4 Collapse of slope of Tokachi river dike (right bank, 3.5 km from river mouth)

Dams

Two survey teams were dispatched to Hokkaido between 1st and 3rd October. The objectives of that investigation were to check the effects of the Tokachi-oki Earthquake on dams, collect the earthquake data at dam sites and collect other measurement data observed at dam sites before and after the earthquake. Table 1 shows the dams at which the survey teams visited and the maximum acceleration recorded at those dams. The inspections by dam owners and our investigation revealed the following effects on dams; some shallow longitudinal cracks at the crest occurred at an embankment dam, the amount of seepage flow in the foundation and/or leakage in the dam body increased temporally at some dams, the turbid seepage flow and/or leakage were observed just after the earthquake at some dam. The extent of these effects was, however, very small and there were nothing to be worried about dam safety.

Table 1 Dams investigated and maximum accelerations

Dam Name	Type*	Height (m)	Year of completion	Horizontal Maximum Acceleration (gal)**	
				Base	Crest
Satsunaigawa	G	114	1998	69	677
Tokachi	R	84.3	1984	43	155
Izarigawa	R	45.5	1980	51	113
Takami	R	120	1983	58	325
Sahoro	G	46.6	1984	82	364
Samani	G	44	1974	—	156***
Urakawa	G	42.1	1999	103	124
Monbetsu	E	20.8	1971	—	—
Bisei	GR	47.2	1999	67 (G), 125 (R)	153 (G), 167 (R)
Azuma	R	38.2	1969	—	—
Mitsuishi	R	35	1991	—	—
Makubetu	E	26.9	During first filling	174	261
Niikappu	R	102.8	1974	20	276
Iwamatsu	G	37.2	1943	72	—
Kuttari	R	27.5	1987	112	196
Horoman No.3	G	42.5	1954	—	—

* G: Concrete Gravity Dam, R: Rockfill Dam, E: Earthfill Dma, GR: Combined Dam (Concrete Gravity Dam and Rockfill Dam)

** Maximum value in two horizontal directions

*** Composed value of two horizontal directions

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Highway Bridges

During the Tokachi-oki Earthquake, some significant damages to the highway bridges including damage to bearings and substructures were developed in the strong motion area. Two types of damage are presented here as a representative damage.

Chiyoda Bridge (Photo 5)

Chiyoda bridge was constructed in 1966 and has 15-span simply-supported girder/truss bridge with total length of 706m. The substructures are wall-type RC columns. The damage was developed at the mid-height sections of RC columns where some of the longitudinal reinforcement is terminated. Photo 5 shows the damage of Pier #13 in which the heaviest damage was found. The cover concrete was spalled-off, and some of the longitudinal reinforcement was buckled at the section. The columns was repaired and strengthened by concrete injection and steel jacketing.

Tokachi River Bridge (Photo 6)

Tokachi river bridge with total length of 926m was completed in 1992. The bridge consists of 3 superstructures with 3-span continuous PC box girders and 3-span PC frame bridge. The substructures consist of wall-type RC columns and pile foundations. The bridge is located close to the fault zone where very strong ground motion was observed. The bearings were failed and the residual displacement of about 70cm in the transverse direction was developed at the continuous box girders as shown in Photo 6. Damage to substructures was not found.

The damage patterns observed during the Tokachi-oki earthquake were the usual type including the damage to bearing, RC columns and expansion joints that were found in the past earthquakes. However, since the strong ground motion data over 500 to 1000gal acceleration on the ground level was observed, further study on the relation between the damage and the strong motion is necessary.

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Photo 5 Damage of wall-type reinforced concrete columns (Chiyoda Bridge. Spall-off of cover concrete was repaired by concrete injection.)



Photo 6 Damage of bearings and transverse residual displacement of deck (about 70cm) (Tokachi River Bridge)

Damage to Road Embankments

We investigated damage to road embankments from Obihiro City to the coast along the National Highway Route 38, and we also surveyed the Route 336, which runs along the coast. The investigated area spreads over the Tokachi Plain, and most parts of those highways are low embankments on soft grounds. The damaged road embankments of the national highways were large in number, however the degree of damage was not so conspicuous, comparing to the damage in the past major earthquakes. The most typical damage was settlement and collapse of road shoulder and sidewalk. The cases in which damage extended to roadways were rather limited. The principal causes of damage to road embankments may be attributed to soft ground, change in topography or embankment structure and existence of a crossing structure underneath a highway. No distinct evidence of liquefaction was observed within the scope of reconnaissance survey. Typical damage to road embankments is briefly described in the following:

Approach of Toyokoro Bridge, National Highway Route 38

This part of the highway is an approximately 10m high embankment that connects with the dike of Tokachi River. A longitudinal crack was observed on the slope of embankment, and the road surface was settled over approximately 15m long (Photo 7).

Chobushi, National Highway Route 336

This portion of the highway is a half-bank and half-cut. The valley-side of embankment is a swamp, and the groundwater level seemed to be high. The sidewalk was collapsed over more than 100m and the roadway was partially damaged (Photo 8).

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Photo 7 Approach of Toyokoro Bridge, National Highway Route 38 (Photo by Hokkaido Development Bureau)



Photo 8 Chobushi, National Highway Route 336

Damage to Port Structures

The major damage of port facilities during the 2003 Tokachi-oki Earthquake is No.4 pier caisson type quay wall (-10m, $k=0.2$) of Kushiro port moved toward sea 10cm to 20cm and large settlement (roughly 0.5m) of apron occurred as shown in Figure 3. The reclaimed material is cement treated dredged fine sands (SPT $N=10$), the PGA at Kushiro port were 575 Gal in EW, 347 Gal in NS and 149 in UD respectively. The key point of the damage mechanism is behavior of backfill rubbles and cement treated soils during the earthquake as follows, 1) the confining pressure of backfill rubbles should be suddenly decreased due to movement of the caisson, 2) then re-arrangement of rubble particles occurred, 3) cement treated fine sands could not follow the deformation of backfill rubbles, 4) large settlement occurred just

behind the caisson body.

During the earthquake, Tomakomai Port was shaken with 70 Gal in EW, 69 Gal in NS and 40 Gal in UD respectively, long period component of 5-8 second and around 180 seconds duration as shown in Figure 4. The cylindrical oil tank (a diameter of 43m, oil depth of 18m and the natural period of first mode of sloshing is 7.1 sec) having floating roof burned due to the earthquake. From the results of back analysis of tank during the earthquake, the maximum uplift of the floating roof occurred 3m at 48sec in EW and 2.3m at 80sec in NS respectively.

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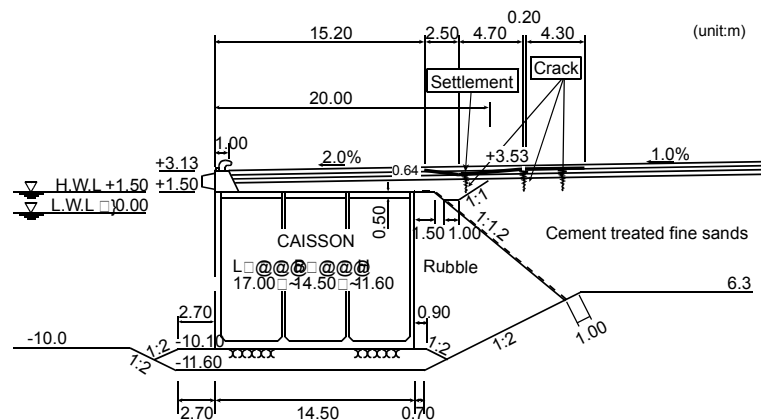


Figure 3 Cross section of -10m caisson type quay wall at Kushiro port No.4 pier

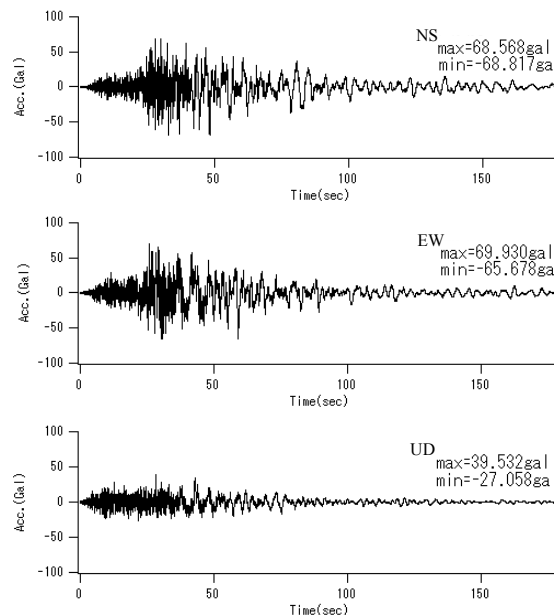


Figure 4 Strong motion records at Tomakomai port during 2003 Tokachi-oki Earthquake

Damage to Sewer Facilities

Sewer facilities in Obihiro area and Kushiro area were severely damaged during the earthquake. The amount of damage to sewer facilities is up to 5 billion yen. The observed damage to the sewer facilities is

mostly uplift of pipes and manholes and settlement of road surface above the damaged pipes as shown in Photo 9. The damaged pipes were constructed by the open-cut method, in which sandy soils were used for backfill. The similar damage to the sewer pipes in Kushiro city and Kushiro town was observed during the 1993 Kushiro-oki earthquake and the 1994 Hokkaido-Toho-Oki earthquake. The most of the damaged pipes were located in wetland, where extremely soft peat soil prevails the ground surface and the ground water levels are shallow. Liquefaction of the backfill soil blow the ground water level was considered to be a major cause of the damage, while amplification of the ground motion at the peat layer was considered to affect the extent of the liquefaction of backfill soil.

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Photo 9 Ejected manhole and settlement of road surface